AUTOSTEREOSCOPIC PROJECTION VIEWER

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[0001]   The United States Government has rights in this invention pursuant to

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BACKGROUND OF THE INVENTION

Field of the Invention

[0002]   The present invention relates to a method and system for producing

stereoscopic images (i.e., one view for each eye of an observer), and more particularly to

an autostereoscopic system and method that produces aberration corrected images with

an apparent size, distance, color and detail to simulate a virtual presence.

Description of Related Art

[0003]   Recently, 3D systems have become of interest because technology has made

3D-like displays a part of daily life. For example, present technology can provide

holographic images on credit cards and on driving licenses. We have home desktop

computers that can generate interactive displays with stereoscopic image pairs. Three

dimensional (3D) arcade games with advanced optical and computer helmet displays

that are available that can produce virtual images.

[0004]   Currently, images provided by conventional 3D viewing systems are too

small or close to appear as full scale. In addition, such systems do not produce images

with the optical characteristics of a real image and often require the need for viewing

aids. Autostereoscopic viewers can provide three-dimensional (3D) images to a viewer

without the need for glasses or other viewing aids. From a viewer's perspective, the

wearing of special glasses is cumbersome and from a provider's perspective, expensive

for such viewing aids. By employing holographic techniques in an autostereoscopic

viewer, special glasses or other viewing aids are no longer a requirement because

virtual 3D effects can be achieved without the need for such ancillary devices.

[0005]   However, while a number of autostereoscopic imaging systems have been

patented and or disclosed in printed publications, none of the related systems disclose a

system tuned for the aberration-free properties with the multiple imaging capabilities

that the present invention provides.

[0006]   Accordingly, a need exists for an autostereoscopic aberration corrected

method and system for producing full-scale virtually real images. Such a method and

system is easy to use by operators and is capable of being implemented in a variety of

commercial and non-commercial applications.

SUMMARY OF THE INVENTION

[0007]   The present invention is directed to an autostereoscopic projection viewer

employed to produce aberration corrected stereoscopic images by employing pairs of

projection optical components coupled with an image corrector plate and a field lens.

[0008]   Another aspect of the present invention is directed to an autostereoscopic

projection viewer employed to produce aberration corrected stereoscopic images by

employing up to three pairs of projection optical components coupled with an image

corrector plate and a pair of Fresnel lenses operating collectively as a field lens.

[0009]   Another aspect of the present invention is directed to an autostereoscopic

projection viewer employed to produce aberration corrected stereoscopic images by

employing pairs of projection optical components coupled with a Fresnel prismatic

beam-splitter, an image corrector plate, and a field lens.

[00010]   A final aspect of the present invention is directed to a method of optically

relaying images from one or more pairs of projection displays to one or more pairs of

optical eyezones and correcting optical aberrations produced by the optical relay,

wherein one or more pairs of stereoscopic images, as seen by the unaided human eye,

are produced.

[00011]   Accordingly, the present system and method provides a desired system and

method capable of stereoscopic vision in recognizing spatial structures and virtual

objects for information and communication systems. It may also be implemented for

displays in simulators, control stations, computer workstations, monitors for

communication, medicine, multimedia and game machines. Optical folding techniques

and software are combined with other aspects of the present invention to produce a

compact package for workstation or arcade use.

BRIEF DESCRIPTION OF THE DRAWINGS

[00012] The accompanying drawings, which are incorporated into and form a part of the disclosure, illustrate an embodiment of the invention and, together with the description, serve to explain the principles of the invention.

Fig. 1 shows a general schematic of an autostereoscopic projection viewer.

Fig. 2 shows a second embodiment of an autostereoscopic projection viewer.

Fig. 3 illustrates a cross-sectional view of a multifaceted Fresnel beamsplitter.

DETAILED DESCRIPTION OF THE INVENTION

[00013] Referring now to the drawings, specific embodiments of the invention are shown. The detailed description of the specific embodiments, together with the general description of the invention, serve to explain the principles of the invention.

[00014] Unless otherwise indicated, all numbers expressing quantities of ingredients, constituents, reaction conditions and so forth used in the specification and claims are to be understood as being modified in all instances by the term "about". Accordingly, unless indicated to the contrary, the numerical parameters set forth in the specification and attached claims are approximations that may vary depending upon the desired properties sought to be obtained by the subject matter presented herein. At the very least, and not as an attempt to limit the application of the doctrine of equivalents to the scope of the claims, each numerical parameter

should at least be construed in light of the number of reported significant digits and by applying ordinary rounding techniques. Notwithstanding that the numerical ranges and parameters setting forth the broad scope of the subject matter presented herein are approximations, the numerical values set forth in the specific examples are reported as precisely as possible. Any numerical value, however, inherently contains certain errors necessarily resulting from the standard deviation found in their respective testing measurements.

General Description

[00015]   The present invention allows direct viewing of three dimensional (3D), full color, aberration (e.g., chromatic, coma, spherical, astigmatism, distortion, and curvature of field aberrations) corrected images that are capable of being viewed by the unaided human eye, i.e., without the requirement of viewing helmets, polaroid glasses, or other viewing aids. The present invention also provides a system and method of projecting images from one or more pairs of projection displays, often 1 pair, more often 3 pairs, such as, CRT's, transparencies, projection sources (e.g., liquid crystal spatial light modulators (LC SLMs)), plasma sources, digital light projectors (DLPs), etc.), and/or flat panel monitors). Three dimension models may also be used to generate stereoscopic views on demand from databases. These images may also be generated from real photos, analog based or digital images or such images may be computer generated. Virtual touring is likely to be accomplished using gaming controls, such as, for example, joysticks, mouse operations, and/or keyboard controls. The tours can be produced for gaming, medical, promotional, or scientific applications.

[00016]   Immersive wide-angle (i.e., up to about 60 degrees) viewing for a single viewer is possible with an optically corrected system disclosed herein. For example, a typical single viewer system might employ a 40" diagonal with the viewer situated 36" in front of a first Fresnel. In another arrangement, an on-axis viewer (having about a 30 degree field of view) can be positioned close to a field lens (i.e., less than about 60 inches) of the system and additional viewers (having less than about a 30 degree field of view) can view their stereoscopic images at positions behind the on-axis viewer by configuring their object and image planes, respectively.

[00017]   The projection system of the present invention also typically employs one or more Fresnel lenses operating as a field lens, one or more pairs of projector lenses, often 1 pair, more often 3 pairs, and an image correcting plate. The role of the field lens is to capture light rays emanating outward from the projection lenses and bring such rays into the zones where the viewers place their eyes. The purpose of a corrector plate is to capture rays that would not arrive at the eyezones and redirect the light to the correct locations (i.e., to the eyezones). The present invention is capable of producing eyezones that a viewer naturally and comfortably can locate, and sustains the ideal viewing position such that all points of an image appear to be uniform in brightness and coloration. A set of ideal eyezones have narrow regions of image overlap between the left and right images of less than about .5 inches. It is desirable that both the left and right eyezones are substantially wide (i.e., greater than about 3 inches) to enable both eyes of a viewer to see either a left or a right monoscopic image. Vertically extended eyezones accommodate all viewers independently of their height or the vertical

movements of their heads. The vertical extent of an eyezone is limited by available

light and the design of the surfaces designed to distribute that light. The forward and

back sensitivity of a viewer's head position depends on the effective field lens (e.g., a

pair of Fresnel lenses) diagonal dimension, focal length, viewing distance, and the

resulting "depth of focus" of the image of the projection lens as produced by an

example pair of Fresnels and related optics. Color tinting of an image in this region is

due to the Fresnel field lenses and is corrected using a custom zone plate designed to

match an assembled system of the present invention.

[00018]   The apertures of the projector lenses are projected as images onto the viewer's

side of a Fresnel operating as a field lens. Thus, the size (e.g., the diameter of the

projector lenses) is a factor in the size of the eyezones in addition to the magnification of

the field lenses' optical image relay. Large lenses are one way to make large eyezones.

Magnifying the image of small lenses is another way to produce large viewing zones.

Square lenses may also be utilized to reduce dark areas between viewing eyezones

because such square geometries allow joining or spacing between collective pairs of

projector lenses of down to about a millimeter, by, for example, trimming such lenses.

High quality projector lenses, i.e., field flattened color corrected multi-element lenses,

are desirable in the present invention because they often produce the highest quality

images. However, Fresnel lenses may also be used as projector lenses in the present

invention depending on the specifications desired by a user.

[00019]   Eyezone size is also a function of the controlled angular divergence of an

imaging surface (i.e., the surface of the corrector/screen/zone plate). If such a surface

receiving the projected images provides three degrees of angular divergence, the images of the projection lenses are spread vertically by that amount over the distance from the corrector/screen/zone to the eyezones. Since all points from the image are directed to all points in the eyezones, the viewing eyezones are vertically enlarged. Thus, vertical extensions of the eyezones are possible using controlled forward "scatter" produced by any suitably textured optical window in the image plane whether produced using holographic, chemical, or mechanical methods.

[00020]   When low brightness projection display sources, such as, conventional CRTs are used, it is desirable to capture as much of the available light as possible using fast lenses (i.e., low f-numbers), such as below about 1.5, to prevent images from being optically defective (e.g., difficult for the unaided human eye to visually see). Such fast lenses having diameters of at least about 2 inches and positioned close (e.g., at least about a focal length) to a light limited projection display, such as, for example, a CRT, a flat panel, or other diffuse luminous image source optimizes the light gathering power of the system.

[00021]   Molding and optical fabrication techniques allow one to directly master or replicate precision optical surfaces and components that are to be utilized in the present invention. Fresnel optical surfaces may be considered as arrangements of small prisms with angles and orientations, often oriented like saw teeth with the same or changing angles. Diffusers may be generally regarded as a random array of prisms, at random angles, pointed in different directions. Holographic elements have features on the scale of lightwaves and interact with the waves themselves via diffraction. This is different

than using diffraction to produce patterns of light to make diffusers that are random prism arrays. The holographic optical elements used in the present invention utilize both refractive and diffractive methods to produce the specialized corrective projection surface.

[00022]   The zonal plate, conjugate corrector, and eyebox projector combination that can make up the image corrector plate of the present invention are produced by holographic techniques, i.e., recordings of light intensity patterns created by the interference of two beams of mutually coherent light. In addition, Fresnel lens flaws can be minimized using a holographic optical element to additionally correct for aberrations, e.g., chromatic aberrations produced by such lenses.

[00023]   The image correcting plate can be designed to be a combination of a zonal plate corrector to correct for chromatic dispersion of the Fresnel lenses, a conjugation corrector to invert phase perturbations produced by the Fresnel lenses, and an eyebox projector to reproduce a viewing window at a predetermined optical eyezone or any combination of the above. The image corrector plate is thus a special holographic optical element (HOE) that can intercept optical rays, often in a plane of the projection displays, and can redirect such rays in a controlled fashion using holographically imprinted information.

[00024]   The image corrector plate is most often a volume hologram, wherein an interference pattern is recorded as a periodic variation in the refractive index of the material while the thickness of the material remains fixed. The periodic variation in the refractive index can create surfaces of peak refractive index within the material and is

created by two or more waves of varying curvature at the hologram surface. However, the corrector plate can also be a blazed hologram wherein the imprinted information is solely on the surface of such an optical element.

[00025]   Materials, such as, but not limited to, silver halide emulsions, hardened dichromated gelatin, ferroelectric crystals, photopolymers, photochromics and photodichroics, are capable of being employed to create such holograms. Dichromated gelatin is most often used to record such holograms in the present invention because such a material has a high-diffraction efficiency (e.g., greater than about 90%) and low noise characteristics (e.g., less than about 3%) that are desired by such applications disclosed in the present invention.

[00026]   The zonal plate aspect of the image correction plate compensates for the undesired dispersive properties of Fresnel lenses made from such materials. Specifically, a zone plate can operate as a diffractive thin lens and can be produced by holographically recording spherical wavefronts from laser point sources. Use of a conventional zone plate does not correct for a system's aspheric aberrations produced by Fresnels as well as a zone plate designed specifically for such a purpose. The dispersive color effects are thus eliminated when such a zone plate is introduced into the system to produce chromatically uniform eyezones. In addition, a zone plate adapted on a predetermined surface of a Fresnel can likewise reduce the dispersion of a specific Fresnel used for producing images.

[00027]   The eyebox projector aspect of the present invention can correct for off-axis astigmatically distorted images produced by fast field lenses using conjugate correction.

A holographic aperture is imprinted in the image corrector plate from a predetermined optical plane within the projection viewer system to create an eyebox projector. Projected light passing through any portion of such a holographic eyebox projector is capable of being redirected at controlled angles to pass through an example field lens, such as, a Fresnel, so as to be received at a predetermined eyezone. Such an operation projects an image of a rectangle into a region where the Fresnels alone would only produce an imperfect focal spot because of, for example, astigmatism, and operates to correct for such an example aberration. While this beam correction can be made about the center wavelength, it can also operate to improve all other predetermined wavelengths. However, multiple wavelength exposure can additionally produce such an element to operate as a white light volume corrector.

[00028]   A Fresnel's focus becomes distorted when an image source is greater than about 10 to about 15 degrees off axis. The use of a predetermined corrector can be designed to redirect the rays distorted by such a field lens (e.g., a Fresnel) so that all points on the image can arrive at the predetermined axis eyezones without such distortions. Specifically, Fresnels points some of the rays in undesired directions. A predetermined corrector redirects projected rays so that after they encounter the Fresnels, they are then capable of arriving at the desired eyezones, i.e., the correction is applied before such an aberration problem is encountered.

[00029]   Holography is a recording of waves of light. The playback of such a recording allows the rays to be recreated and sent along their original direction or in the reverse path. This method allows one to focus a laser in front of a number of imperfect optics,

pass the light though those optics, record the blur spot, playback the hologram in reverse through the imperfect optics, and project a substantially perfect image of the focused laser back upon its source. This method is known in the art as phase conjugate correction.

[00030]   The conjugation corrector aspect of the image correction plate also requires the Fresnel(s) when holographically imprinting the information of the optical aberrations produced from such lenses. To create such an aspect of the optical element, a pattern of light is produced that is approximately the size of a designed eyebox and is located in an eyebox position in relation to the Fresnels. Specifically, light is designed to pass from a predetermined "eyezone" through the Fresnels and onto a predetermined plane where a holographic "plate" (e.g., the image corrector plate) is located to record the optical path of light through such Fresnels. Recording this requires the use of a "reference beam" that does not have the optical flaws introduced by the system. A lack of space between the Fresnel and the corrector plate requires the recording of the Fresnel wavefront substantially near its focus to allow room to inject the reference beam to produce the first hologram. This hologram is played back using a reversed reference beam to project an image of the Fresnel back upon itself such that a corrected image of a point of light in front of the Fresnel is capable of being produced. The reversed playback condition allows the production of the corrector plate by recording the playback with a reference beam. If the radius of curvature of the reference beam is properly considered, a zone plate is produced that can also correct for the dispersion of the Fresnels. When making this hologram, an array of points is used in

the shape of a desired eyebox with separate recordings made for the on-axis and off-axis rays.

[00031]   Since each point of light can produce a shadow of a Fresnel, it is desirable to have a sufficient number of points, e.g., by producing light from a diffuser, such that the shadows of the Fresnel are so numerous and distributed that they can cancel any faults in the finished optical element. Specifically, the reverse through this element when utilized in the present invention produces a redirection of the rays to correct the aberrations for a viewer.

[00032]   Immersive wide-angle (i.e., approximately a 60 degree diagonal) viewing for a single viewer is possible with an optically corrected system disclosed herein. A multi-viewer system positions an on-axis viewer (having about a 30 degree field of view) further from the field lens (i.e., at least about 60 inches). Additional viewers (having less than about 30 degree field of views) view their stereoscopic images at positions behind the on-axis viewer by configuring their object (i.e., a respective projection display) and image planes, respectively.

[00033]   The present invention may also employ diffusers, lenticular screens to enlarge optical exit pupils (i.e., eye zones), and/or prismatic Fresnel beam-splitters as an additional means to provide multiple large eye-zones for viewers.

[00034]   Moreover, such a system of the present invention can be operationally computer-controlled to manipulate images and/or to make hardware adjustments of individual optical components to compensate for various users optical viewing

differences and/or for optimizing the system. For example, the use of a digital pan and zoom allows the user great flexibility in viewing the images. Keyboard controls, such as arrow keys, may be used to control viewer position. Other keys may be used to adjust the relative position of the images in relation to each other for the purpose of "vergence" control, vertical offset, rotation, or distortion correction. In addition, the positioning of the pair of images and their window(s) may be computer software-controlled.

Specific Description

[00035] A viewing distance (i.e., an eye relief) of the present invention is at least about the diagonal of a field lens (e.g., a dimension of at least about 15 inches). A viewer sees at least greater than about a 1:1.2 magnified and apparently distant, stereoscopic image from a predetermined optical component, such as, for example, an image corrector plate, a prismatic Fresnel beamsplitter, an optical conjugator, a screen, such as, a lenticular array and/or an optical diffuser, or any optical element arranged to be in a designed optical plane before an example field lens (e.g., about 1/6 of a field lens focal length). Because the image plane appears behind the Fresnels it is magnified and appears more distant than it actually is.

[00036] The viewer only sees the pair of images when their eyes are properly positioned in a pair of predetermined eyezones. The predetermined eyebox or diffuser properties, the size of the projection lenses, and any magnification of a field lens determine the size of each of the one or more pairs of eyezones.

[00037]   A single Fresnel lens can be employed for the "finite conjugate" of the present

invention when utilized as the field lens (a field lens increases the field of view without

increasing the dimensions of a predetermined lens, e.g., optical eyezone). More often, a

pair of "infinite conjugate" Fresnels may be used to make a single fast Fresnel. A

separation from about 3 to about 5 inches between the two lenses has the effect of

reducing the alignment of the concentric structure in the lenses, thus minimizing moire

effects (i.e., the spurious patterns resulting from the interference beats between two or

more sets of periodic structures in an image) between the lenses and possible additional

moire effects which can occur from the optical information produced by the pixels from

projection displays (e.g., CRTs) disclosed in the present invention.

[00038]   To obtain large diameter lenses of at least about ½ meter diagonal with fast f-

numbers, Fresnel lenses of the present invention are conventionally made from a

material, such as, acrylic, or styrene because such lenses are light, easily manufactured,

and are cost effective. However, such lenses have chromatic dispersive properties that

often require correcting when employed in an optical imaging system. Newly

developed resin materials that have high UV light transmission of up to about 92% with

low optical dispersion (i.e., abbe numbers of 56) may be a way of making Fresnel lenses

so as to reduce the chromatic aberration problems that occur with materials such as

acrylic or styrene.

[00039]   The present invention can have eyezones of at least greater than about 1 inch

along the long axis dimension but more often the present invention is designed to have

eyezones of between about 4 inches wide and about 24 inches high for each eye to allow

a user to comfortably and easily position oneself such that optically relayed stereoscopic images of a projection display can be seen. In addition, example eyezones that are four inches wide can provide a monoscopic image for both eyes of a viewer, a situation that is more desirable than darkness in one eye when the viewer is off-axis.

[00040]   Fig. 1 illustrates an example embodiment of an autostereoscopic projection viewer, often designed for 3 viewers, and is generally designated by the reference numeral **10**. Such an example embodiment shows an optical axis, denoted as **O**, a pair of left and right substantially on-axis projection displays **2L, 2R**, (i.e., a center of such a display is at least about .5″ off-axis and a center to center of such pairs of displays is at least about 1″), a pair of substantially on-axis projection lenses **6L, 6R**, at least one pair of left and right of up to about 60 degrees off-axis projection displays **12L, 12R**, such as, for example, CRT's, transparencies, photographs, projection sources (e.g., liquid crystal spatial light modulators (LC SLMs)), transparencies, plasma sources, digital light projectors (DLPs), etc.), flat panel monitors, or any other projection display with sufficient intensity to produce an image by the present invention and at least one pair of left and right off-axis respective projection lenses **16L, 16R**.

[00041]   In addition, autostereoscopic projection viewer **10** can employ an image corrector plate **20** arranged at about the focal plane of a projected image, i.e., up to about 5 inches from the nearest field lens **24**, (shown as a dashed rectangle), such as, for example, at least one Fresnel lens, more often a pair of Fresnel lenses **26**, that can operate collectively as a field lens such that pairs of eye-zones, e.g., right and left off-axis eye-zones **28R, 28L** and right and left substantially on-axis eye-zones **32R and 32L**

are capable of being produced at distances from the last surface of field lens **24** of at least about a diagonal measured value of the long axis of field lens **24** (i.e., at least about 15 inches).

[00042] **Fig. 1** illustrates an example embodiment wherein illustrative optical rays, e.g., **A**, **B**, **C** and **D**, of viewer **10**, are directed from left to right without being redirected from an highly reflective optical element, e.g., one or more turning mirrors. However, as another embodiment, one or more a pairs of mirrors, having reflectivities of at least 90%, are capable of being arranged within the optical relay of **Fig. 1** such the optical rays from each display can make one or more angular turns of up to about 90 degrees, and/or as another example, projection displays, such as, DLPs, LC SLMs, plasma sources, etc., may be designed to face each other in conjunction with one or more a pairs of highly reflective mirrors such the optical rays from each display can make one or more angular turns of up to about 90 degrees to produce a compact version of the viewer shown in **Fig. 1**. In addition, as another arrangement, projection viewer **10**, as shown in **Fig. 1**, is capable of being designed to provide for solely an on-axis user, (e.g., a user observing stereoscopic images located at eyezones **32R** and **32L**) to simplify the system and save on component costs (i.e., limit the number of projection displays and projector lenses and scale down the size of optics, such as, for example the size of the Fresnel lenses).

[00043] In the method of the invention, referring to **Fig. 1**, example off-axis projection display **12R**, which is one half of the off-axis display pair **12L** and **12R**, is designed to emit photons such that an off-axis viewer (e.g., shown as eyezone **28R**) can observe

images produced by projection display **12R**. Image corrector plate **20** is arranged at about the image plane of projector lens **16R** so as to receive photons emitted by projection display **12R**, shown as a pair of optical rays **A** and **B**, after being directed by off-axis projector lens **16R**. Chromatic components inherent in an example projection display **12R**, shown as spatially dispersed rays **AA'** (shown as a solid line) **AAA'** (shown as a dotted line) and **BB'** (shown as a solid line), **BBB'** (shown as a dotted line) respectively, are received by, for example, pair of Fresnel lens **26**, and are further directed as shown by rays **AA"** (shown as a solid line), **AAA"** (shown as a dotted line) and **BB"** (shown as a solid line), **BBB"** (shown as a dotted line) to a respective eye-zone **28R**. For example, **AA', AA"** and **BB', BB"** can be the blue wavelength components (i.e., higher frequency) that is included in rays **A** and **B** respectively and **AAA', AAA"** and **BBB', BBB"** the red wavelength components that is included in rays **A** and **B** respectively (i.e., lower wavelength)

[00044]   Correspondingly, substantially on-axis projection display **2L**, which is one half of substantially on-axis projection display pair **2L** and **2R**, and substantially on-axis projector lens **6L** are arranged such that an on-axis viewer (shown as eyezones, e.g. **32L, 32R**) can observe images produced by projection display **2L** within eye-zone **32L**. Here, image corrector plate **20** can receive photons emitted by projection display **2L**, shown as a pair of optical rays **C** and **D**, after being directed by off-axis projector lens **6L**. Chromatic components inherent in rays **C** and **D**, as similarly discussed for rays **A** and **B**, are redirected by plate **20**, as shown as spatially dispersed rays **CC'** (shown as a solid line), **CCC'** (shown as a dotted line) and **DD'** (shown as a solid line), **DDD'** (shown as a

dotted line) respectively. Such rays are then received by pair of Fresnel lens **26**, and are further directed, as shown by rays **CC"**(shown as a solid line), **CCC"** (shown as a dotted line) and **DD"** (shown as a solid line), **DDD"** (shown as a dotted line), to a respective eye-zone **32L**.

[00045] Multiple projection displays, as shown in **Fig. 1**, is an example embodiment of allowing multiple viewers to use the same field lens, e.g., pair of Fresnel lenses **26**. Often, users, such as, video gamers want to interact, i.e., play, with others while sharing a divided screen. Thus, dividing viewing eyezones in the present invention, as shown in **Fig. 1**, provides a different but stereo view to all of the players. Such an embodiment is beneficial because individual players can be networked onto a single game and each has their own screen. It is also beneficial that the present invention is capable of adjusting optical components to produce optimized images for individual users. Such adjustments can include, but is not limited to, computer controlled digital pan and zoom of the images, keyboard controls, such as, arrow keys, may be used to control viewer position or to adjust the relative position of the images in relation to each other for the purpose of "vergence" control, vertical offset, rotation, or distortion correction.

[00046] Horizontal keystone correction is required for such multiple display off-axis projection systems. This is the condition where the off-axis projection displays are decentered from a respective projector lens but each projector lens and the image planes produced by such projector lenses are parallel and square to each other. A projection display on-axis (i.e., aligned on the optical axis) does not have this issue but off-axis and even substantially on-axis systems projects trapezoidal images. To correct the image,

the eyezones are tilted by up to about 60 degrees, as shown by **28R** and **28L** in **Fig. 1**, in

relation to respective projector lenses to correct for the off-axis trapezoidal aberration.

[00047]   Keystone correction is conventionally used to correct for vertical off-axis

conditions but is also applicable to the off-axis horizontal embodiment of the present

invention. This is especially true for a pair of off-axis eyezones but since all of the

eyezones are off-axis even in the substantially on-axis viewing position, e.g., as shown

by **32R** and **32L** in **Fig. 1**, this kind of correction ensures that all are in proper

stereoscopic registration (i.e., rectangle on rectangle – not trapazoid on mirrored

trapezoid).

[00048]   An alternate example autostereoscopic projection viewer, often designed for

up to about 3 viewers, is shown in **Fig. 2** and is generally designated by the reference

numeral **100**. In this arrangement a Fresnel prismatic beamsplitter can by added in

addition to the image corrector plate, as described and shown in **Fig. 1**, to enable at least

a pair of substantially on-axis projection displays to be the sole source of allowing one

or more viewers to observe stereoscopic images produced by such displays. Such a

Fresnel prismatic beam-splitter is used to send a stereoscopic image towards one or

more observer's eyes. Such an optical element has portions that are a multi-faceted

window to the through rays to present an image to a viewer stationed on axis. The

surface of the element also has an array of parallel prisms to direct light to eyezones on

either or both sides of the on axis viewer.

[00049]   The example embodiment of **Fig. 2** shows an optical axis, denoted as **O**, a pair

of left and right substantially on-axis projection displays **102L**, **102R**, a pair of left and

right substantially on-axis projector lenses **106L, 106R,** a Fresnel prismatic beam-splitter **120** arranged at about the projected image plane of projector lenses **106L, 106R** (i.e., a magnified image from projector lenses **106L, 106R**), an image corrector plate **122** capable of operating as an optical diffuser, and a field lens **124** (shown as a dashed rectangle), such as, for example, at least one Fresnel lens, more often a pair of Fresnel lenses **126,** that can operate collectively as a field lens such that one or more pairs of eyezones, e.g., right and left off-axis eyezones **128R, 128L, 130R** and **130L,** and right and left substantially on-axis eye-zones **132R** and **132L** are capable of being produced at distances of at least about 8 inches (i.e., typically the diagonal of a field lens) from the last surface of field lens **124.** However, as another embodiment, image corrector plate **122** can be removed from projection viewer **100** and longer field lens focal lengths can be utilized to constrain the angular views to between about 10 and about 15 degrees such that off-axis aberrations produced by Fresnel prismatic beam-splitter **120** are minimized.

[00050] Lenticular screens (i.e., a flat arrangement of many cylindrical lenses (lenticules) which direct the light of all the pixels selectively into dedicated viewing areas) can also be added to such an arrangement to increase the size of eyezones (typically in the vertical dimensions) and to add comfort to a viewer positioned at eyezone locations. In addition, the image corrector plate can be designed to operate as a holographic optical diffuser or a predetermined optical diffuser can replace the image corrector plate when made from materials, such as, matte finished etched glass, texturized plastic films, and embossed films. Each diffuser can be selected, designed, or

modified to provide the controlled forward scatter optimize for the lenses and brightness available.

[00051]   Turning again to the figures, **Fig. 2** illustrates an example multi-viewing arrangement wherein projection display pair **102L, 102R,** are configured in viewer **100** such that on-axis (e.g., eyezones **132R, 132L**) and off-axis observers (e.g., eyezones **128R, 128L**) are capable of viewing stereoscopic images produced by such displays. In such an embodiment, Fresnel prismatic beamsplitter **120** and image corrector plate **122** are collectively arranged to receive directed photons by projector lens pair **106R, 106L,** shown as optical rays **G** and **H,** and to direct such rays to pairs of eyezones without predetermined optical aberrations, such as, but not limited to, chromatic, coma, spherical, astigmatism, distortion, and curvature of field. For simplicity, the correction for the chromatic components produced by viewer **100,** as shown in **Fig. 2,** is similar to the discussion for the embodiment, as shown in **Fig. 1,** when utilizing image corrector plate **122.** Therefore, chromatic ray analysis is omitted in the discussion for the embodiment of in **Fig. 2** to illustrate the multi-viewing positions produced by prismatic beamsplitter **120** in autosteroscopic projection viewer **100.**

[00052]   In the method of the arrangement shown in **Fig. 2,** Fresnel prismatic beamsplitter **120,** positioned in a common image plane of projector lenses **106R** and **106L,** can receive example optical rays **G,** and **H** and can deviate such rays primarily dependent on predetermined angles of incidence and the location such rays make with respect to the multi-faceted output surface (not shown) of Fresnel beamsplitter **120.** As examples, ray **G** can be transmitted as a deviated or an undeviated ray after being

received by Fresnel beamsplitter **120** and after correction as discussed above by image

corrector plate **122**, as shown by undeviated ray **GA** (shown as a dashed line) or

deviated ray **GB** (shown as a solid line). Ray **H** can additionally be transmitted as a

deviated or an undeviated ray after being received by Fresnel beamsplitter **120** and

after correction as discussed above by image corrector plate **122**, as shown by

undeviated ray **HA** (shown as a dashed line) or deviated ray **HB** (shown as a solid line).

Such rays then proceed through viewer **100** as shown by rays **GA′, GB′, HA′, HB′** after

being received by field lens **124** and are redirected to designed eyezones (e.g., **128R**,

128L, and **128R**, **128L**), to provide for stereoscopic images.

[00053]   The embodiment, as shown in **Fig. 2**, similar to the embodiment, as shown in

Fig. 1, can also include one or more a pairs of highly reflective mirrors arranged such

that the optical rays from each display can make one or more angular turns of up to

about 90 degrees, and/or as another example, projection displays, such as, DLPs, LC

SLMs, plasma sources, etc., may also be arranged to face each other in conjunction with

one or more a pairs of highly reflective mirrors such that the optical rays from each

display can make one or more angular turns of up to about 90 degrees to produce a

compact version of the viewer, as shown in **Fig. 2.**

[00054]   **Fig. 3** illustrates in cross-section, such a multifaceted Fresnel beamsplitter **120**,

as discussed above, having substantially flat surfaces **150**, and designed prismatic

surfaces **160, 162**, and having a predetermined index of material so as to be capable of

directing optical light rays to eyezones on either or both sides of an on-axis observer

(not shown). As examples, an optical ray **164**, (e.g., a ray collinear with optical axis **O** as

shown in **Fig. 2**) having an incidence angle θ (defined by an angle ray **164** makes with a normal **N**, as denoted by a dotted line, to prismatic surface **160**) is deviated (ray **164** if is shown as ray **164′**) by an angle θ′, as shown by ray **165** according to Snell's law (nsinθ = n′sinθ′, where n is the index of the first medium, and n′ is the index as seen by a transmitted ray). However, an optical ray **168**, (e.g., an optical ray also collinear with optical axis **O**, as shown in **Fig. 2**) that is received normal to substantially flat surface **150** is capable of being transmitted as an undeviated ray **168′** wherein such a ray is capable of being directed by the projection viewer, as shown in **Fig. 2**, to an on-axis observer. To further illustrate the directional properties of Fresnel beamsplitter **120**, example optical rays **170** and **174** (undeviated rays are shown as rays **170′** and **174′**) that are, for example, non-collinear with ray **168** but parallel to each other, can be deviated, as shown by rays **171** and **175**, by prismatic surfaces **160**, **162** respectively, and are capable of being directed, for example, to eyezones on either or both sides of an on-axis observer.

[00055] It should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.